THE SYSTEMS ENGINEERING CAPABILITY MATURITY MODEL: WHERE TO START?

Kerinia Cusick
14742 Beach Blvd, #405
La Mirada, CA 90638-4217

Abstract

The Systems Engineering Capability Maturity Model is a tool designed to help companies measure and improve their system engineering processes. The architecture of the model is designed to provide the user with a lot of flexibility, and to not be overly prescriptive with regards to how companies should structure their improvement plans. However, the result is that the Systems Engineering Capability Maturity Model can appear overly complex, leaving potential users confused and unable to develop an effective plan of attack for deploying the model within their own companies. By analyzing the data within the Systems Engineering Capability Maturity Model one can organize the model content by level of difficulty or complexity. The author has organized the model content into five stages of difficulty, termed Improvement Stages. Organizations can use these Improvement Stages as an additional data point or as guidance when they are evaluating or improving systems engineering processes.

Introduction

Many companies are interested in using the Systems Engineering Capability Maturity Modelsm (SE-CMMsm) but are daunted by the flexible architecture of the model. Contrary to other maturity models with which more are familiar, such as the CMM for Software, the architecture of the SE-CMM1 allows the user a lot of autonomy in determining which aspects of systems engineering on which to first focus. Some companies appreciate this flexibility while others would prefer for the model to include strict process improvement guidance.

The SE-CMM was developed by a collaboration of systems engineering, modeling and assessment experts to provide industry with a tool designed to facilitate the improvement of systems engineering processes. The industrial collaboration, called EPIC (Enterprise Process Improvement Collaboration), included GTE, Hughes, Loral, Lockheed, Software Engineering Institute (SEI), Software Productivity Consortium and Texas Instruments.

The SE-CMM is a tool which can be used in a variety of ways depending upon the goals of the organization using it. It can be used as guidance in developing documented or undocumented processes, or to measure implemented processes and determine targets for improvement, or to establish criteria used as part of selecting a contractor or subcontractor.

This paper explains the SE-CMM architecture, reviews the content of the model, and explains the typical pitfalls that users encounter when trying to adopt the model and use it to establish organizational goals or measure improvement. A method of avoiding the pitfalls, and using the author's Improvement Stages is discussed, along with the limitations of the method.

Model Description

The SE-CMM describes the essential systems engineering and management tasks that any organization needs to perform. These essential tasks are organized into logical groupings which are called Process Areas. A listing of the 18 Process Areas in the model, along with a very brief description is included in Table 1. How these essential systems engineering tasks are performed can range from completely ad hoc to using coherent management processes to guide and control the work. The progression from ad hoc to coherent management is broken into 5 primary steps, called Capability Levels in the SE-CMM, where each step lays the foundation for the next.

The concepts of gradual organizational improvement embedded in the Capability Levels have been used for over 10 years. There is a significant amount of empirical data which shows that the

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[sm] Capability Maturity Model and CMM are service marks of Carnegie Mellon University

gradual improvement and change prescribed via the Capability Levels is sound. Table 2 summarizes the five Capability Levels in the SE-CMM and the key concepts associated with each level.

The Capability Levels are designed to address some of the cultural problems inherent in organizational change and learning. It is very difficult to get an organization under control, sharing learned experiences, aligned to a common vision, and using common tools. However, many companies make the mistake of jumping right in, trying to force organizational change without really trying to address the problems that people working on projects face or trying to get their buy-in. The concepts in Capability Levels 2 and 3 are designed to force organizations to work with the projects by learning from the projects and gathering processes that have been proven successful by the projects to create organizational standard processes and tools. Trying to bypass the projects, and developing an organizational standard process without the collaboration of the projects is typically disastrous. Projects are typically wary of using an organizational standard that has no data indicating its effectiveness. Having no data to prove that this organizational process is a successful way of operating, the project resist and the organizational standard process deployment effort is derailed.

Process Area Title	**Process Area Description**
Analyze Candidate Solutions	Perform studies and analyses which result in the selection of a solution to meet the specified constraints.
Derive and Allocate Requirements	Analyze the sys. & other req. & derive a more detailed & precise set of req, allocate to sys. fnct., people, supporting processes, products & services, which can be used to synthesize soln.
Evolve System Architecture	Transform the functional architecture into the physical architecture for the system and evaluate the impact of design decisions on life cycle costs, manufacturability, and supportability
Integrate Disciplines	Identify those disciplines necessary for effective system development and create an environment in which they can work together effectively toward a common agenda.
Integrate System	Ensure the system elements will function as a whole.
Understand Customer Needs & Expectations	Elicit, stimulate, analyze, & communicate customer needs & expectations to obtain better understanding of what will satisfy the customer.
Verify and Validate System	Ensure that the team performs increasingly comprehensive evaluations to ensure that evolving work products will meet all requirements.
Ensure Quality	Address not only the quality of the system, but also the quality of the process being used to create the system and the degree to which the project follows the defined process.
Manage Configurations	Maintain data and status of identified configuration units, and analyze and control changes to the system and its configuration units.
Manage Risk	ID, assess, monitor, & mitigate risks to the success of the SE activities the overall tech. effort.
Mntr & Cntrl Tech Efrt.	Provide adequate visibility into actual progress and risks.
Plan Technical Effort	Establish plans that provide the basis for scheduling, costing, controlling, tracking and negotiating the nature and scope of the technical work.
Define Org. SE Process	Create and manage organization's standard systems engineering processes.
Improve Org. SE Processes	Gain competitive advantage by continuously improving the effectiveness and efficiency of the SE processes used by the organization.
Mange Product Line Evolution	Establish and provide the necessary resources for acquiring, developing, and applying technology to a product line for competitive advantage.
Manage SE Support Environment	Provide the technology environment needed to develop the product and perform the process.
Provide Skills and Knowledge	Provide the organization with the necessary skills to perform the work using all project needs and organizational goals as the basis for the needs.
Coordinate with Suppliers	Provide suppliers with clear expectations and measures of effectiveness. Communicate frequently with suppliers.

Table 1- Listing of the SE-CMM Process Areas

Capability Level	Primary Concept	Characterized By	Achieved When
0: Not Performed	Organizational starting point	-	-
1: Performed Informally	Doing the task	Individual heroics, significant overtime, informal processes	The systems engineering or management tasks are done
2: Planned & Tracked	Controlling local chaos- getting control on projects	Instilling discipline on the projects, capturing project processes to create the organizational standard	Each project is using a defined (i.e. documented) process. Each project process may be unique
3: Well Defined	Using the best of the project processes to create and org. standard	The development & deployment of an organizational standard, significant increase in reuse and ability to share resources	Project start with the organizational standard and tailor it to create their project unique process
4: Quanti-tatively Controlled	Managing processes using data and trends	The definition of quantitative quality goals for products, using stat. process control methods for capturing & analyzing data	Each project is capturing metrics and using the data to manage the processes
5: Conti-nuously Improving	Improving processes using the data and trends	Quantitative goals for processes based on business objectives	Organizational processes are being continuously improved

Table 2- Summary of Capability Level Key Points

Measuring the implemented systems engineering processes to determine how well they are being managed (i.e. determine the Capability Level) is done in an assessment, where the organization's processes are evaluated against the list of essential tasks contained in the model. The assessment methodology was developed concurrent with the model, but published in a separate document, the SE-CMM Assessment Method[2]. In an assessment one determines if the SE-CMM practices are being performed. Depending upon which specific subset of systems engineering and management practices are being performed establishes the Capability Level at which a Process Area is being performed.

Flexibility of the Model

The SE-CMM architecture allows the user to decide which are the essential systems engineering tasks (the Process Areas) that are most important to their line of work, and decide how well they want to be managing those essential tasks (i.e. at what Capability Level do they want to be performing the Process Area). Since there are 18 Process Areas in the model the user has a lot of autonomy, but also a lot of decisions to make.

Figure 1 demonstrates this point by showing the result of a sample SE-CMM Assessment. Down the left hand side are the list of 18 process areas, each with a capability level score that ranges between 0 and 5.

Users of the model frequently use a desired rating profile to help set goals for the organization. For example, a leader will use the model, and their view of the future needs of the organization, to decide that in two years that the organization should be performing a specific subset of Process Areas at Capability Level 2, and another subset of Process Areas at Capability Level 3, etc. Assessments are used to determine the gap to the goal, and over time progress towards meeting the goals.

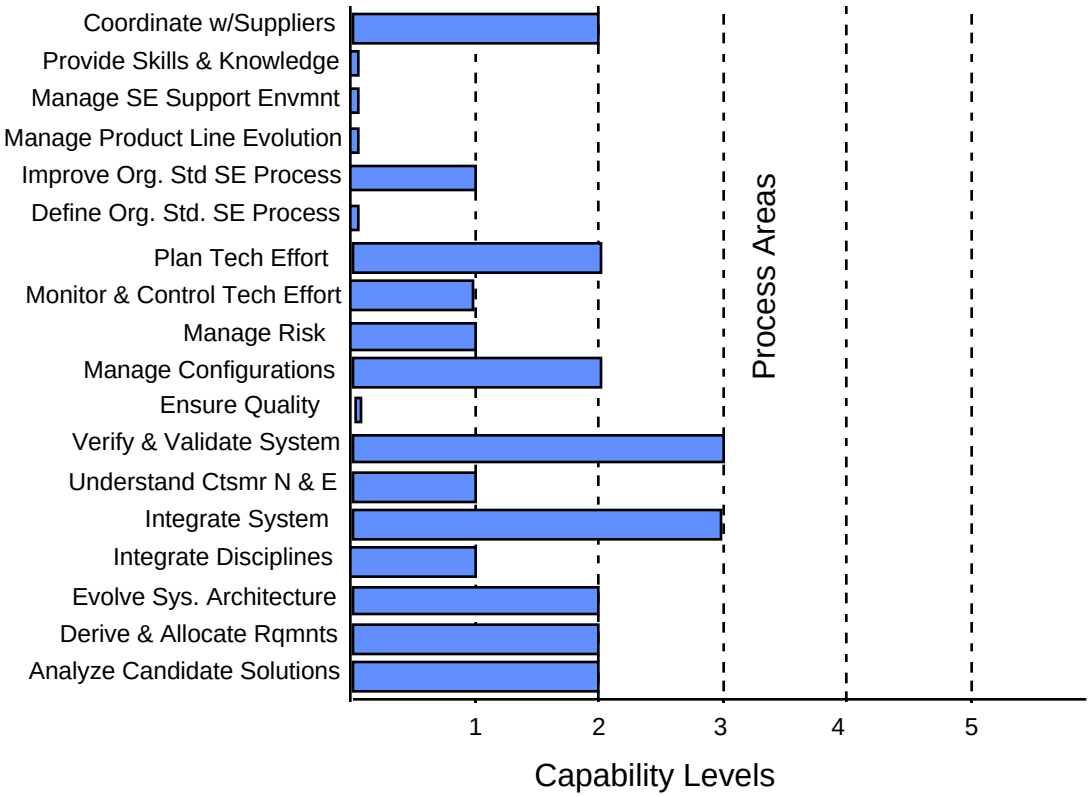

Figure 1- Sample SE-CMM Assessment Result

Complexity of the Model

However, what most users don't realize is that some of the Process Areas are more difficult for an organization to do than others. Some of the tasks described in the Process Area are inherently more complex than others in that they have a broader scope, require participation from all levels in the company, or are based on a detailed understanding of an organization's ability to develop a product. For example, the practices detailed in the Process Area called Provide Skills and Knowledge requires organizations to determine the skills needed by the entire organization considering the needs of all of the projects and the future goals of the company. This is a difficult Process Area for organizations to perform since it requires having a complete view of the needs of all of the projects and knowing how the company wants to position itself in the future to better meet their customer needs and/or improve their profit share.

An analogy is comparing the systems engineering Process Areas to educational classes. Some of the process areas are at the high school level while others would be completed as part of a doctoral program. And it is clear that one cannot draw conclusions about the level of difficulty or mastery required by comparing an "A" in a high school class with a "B" in a doctoral class.

Therefore, while the architecture provides companies with the flexibility to determine their priorities, the complexity of the content of the Process Areas needs to be considered in setting goals.

Improvement Stages

Since the Capability Levels are designed to represent a gradual progression of improved management and processes, mapping the Process Areas to the concepts inherent in the Capability Levels provides an excellent method of organizing the Process Areas by level of complexity.

Capability Level 1 is characterized by ad hoc performance, therefore the Process Areas that address doing the systems engineering activities map to Level 1. Capability Level 2 is characterized by project management, and the project management process areas map very cleanly to Level 2. Capability Level

3 is characterized by deployment and use of organizational standards, an aligned organization. Therefore all of the Process Areas that discuss organizational wide activities or the development of standards map to Level 3. Capability Level 4 is characterized by statistical process control, therefore the Process Area that discusses measuring process quality quantitatively maps to Level 4. Capability Level 5 is characterized by continuous improvement, therefore the Process Area that addresses improving the standard process maps to Level 5.

Figure 2 shows the result of mapping the SE-CMM process areas to the capability level concepts. To avoid confusion with other terminology, we call the result of this mapping "Improvement Stages".

Bringing the process areas that focus on "doing systems engineering" (e.g. Analyze Candidate Solutions to Coordinate with Suppliers) to a capability level 1, is the easiest activity, which we call Improvement Stage 1. Improvement Stage 2 involves adding the project management process areas (e.g. Integrate Disciplines to Plan Technical Effort) and performing all of these process areas (e.g. Analyze Candidate Solutions to Plan Technical Effort) at a capability level 2. This is incrementally harder and the next logical step in overall improvement. The same concept of adding process areas and performing all of them at higher capability levels continues through Improvement Stage 5.

While some process areas map very nicely to one level, the concepts in some other process areas span multiple maturity levels. The Ensure Quality process area is the primary example. Examining the content of the process area one can see that it includes examining the quality of the product and the quality of the process. Measuring the quality of the process is an Capability Level 4 concept, while quality of the product maps to Level 2. To avoid forcing organizations to find methods of measuring process quality that do not make business sense, this process area was placed at Improvement Stage 4.

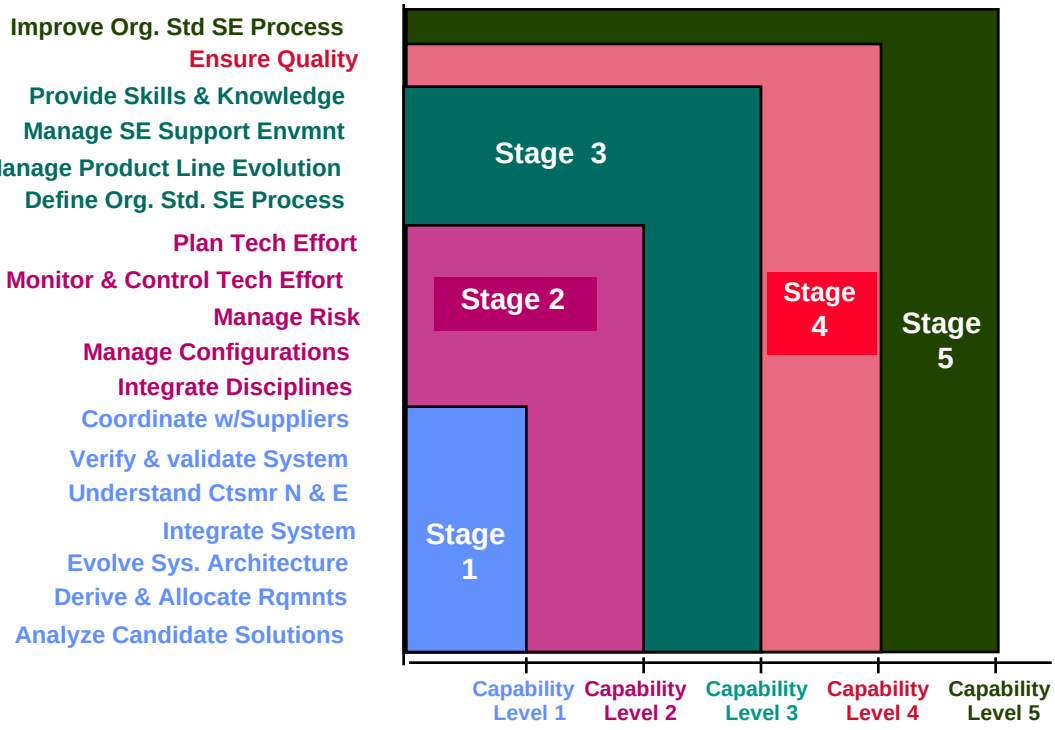

Figure 2- Improvement Stages

There is no intent to show an exact sequence for how a company would go about tackling each of these process areas in the Improvement Stages. Improvement Stages provide additional guidance, arranging the SE-CMM processes areas by order of difficulty.

An analogy is to a ski slope map. The SE-CMM process areas are similar to a map showing the only the location of trails on a mountain. Viewing this map the skier sees their options, knows how many slopes they are, but knows nothing of the level of difficulty. The Improvement Stages is similar to the overlay of green circles, blue squares and black diamonds on the map of each of the ski trails. Now the skier has the additional detail, knowing which trails are appropriate for beginners, intermediates and advanced skiers.

Deciding upon the order in which to tackle the process area, or developing an implementation plan, is similar to making the decision to learn to ski. In the SE-CMM the goal is a specific profile or Improvement Stage. The ski goal is the advanced, black diamond slope. You must progress through the beginner and intermediate slopes, learning skills along the way before trying the advanced slopes. You must learn specific skills such as to how to balance on skis, turning, stopping, falling and getting up. Learning to be proficient in one skill may take longer than mastering another. You learn and practice a skill on an easy slope, in anticipation of the skills that are going to be required at the next level of difficulty. And, of course the skills must be learned together. It doesn't do you much good to be very good at turning if you can't stop when you get to that black diamond slope.

When adopting the SE-CMM, many companies find that they need to start developing methods of addressing the quality of processes early on, learning the skill of measuring process quality in anticipation of performing that activity at higher maturity levels. Companies need to learn a variety of skills including planning, tracking progress against plans, establishing and achieving product and process quality goals, etc. And, of course, organizations find that having an organizational standard doesn't do them much good without an infrastructure to support the deployment of that organizational standard.

The analogy continues, in that you can always start skiing on the advanced slopes as a beginner, but the odds are good that you're going to break your neck. A company can choose to tackle a hard process area first, but the odds are that they will spend a lot of time recuperating from the mistake of no return on investment and not achieving expectations.

Therefore, the Improvement Stages are critical information in helping an organization develop its own implementation plan, but they are not an exact sequence to follow. They provide a snapshot. A measure as to where the organization stands, and general guidance on what set of process areas for which they are ready.

The SE-CMM has been used in the acquisition process. The Improvement Stages provide a straight forward method of using the SE-CMM as a criteria. The contracting organization can specify a desired Improvement Stages versus having to specify a desired profile.

Conclusions

The SE-CMM is an effective systems engineering process measurement and improvement tool. However, it presents the users with flexibility that can be harmful if not enough time is spent to understand the content of the model and the complexity of the individual practices within each of the Process Areas.

The Improvement Stages structure the SE-CMM by order of difficulty, encouraging companies to focus on learning the basics of systems engineering before tackling effective project management or trying to deploy an organizational standard. Improvement Stages help minimize the confusion associated with adopting the SE-CMM, providing companies with recommendations of what to focus on first.

Improvement Stages also minimize the possibility for misuse of the SE-CMM in an acquisition environment. Procuring organizations familiar with the CMM for Software may be inclined to require a contractor to perform all process areas at a capability level 3, and not be aware that this is not quite logical in the SE-CMM architecture. Improvement Stages map the process areas to capability level concepts, providing the SE-CMM equivalent of the maturity levels in the CMM for Software. Therefore, if a procuring organization was tempted to use the SE-CMM in a acquisition environment, one method would be to specify a desired SE-CMM Improvement Stage as outlined in this paper.

References

[1] Bate, R., et al. "A Systems Engineering Capability Maturity Model", Version 1.1, 1995.

[2] Garcia, S., et al. "A Description of the Systems Engineering Capability Maturity Model Appraisal Method", Version 1.1, 1996.

Author Biography

Kerinia Cusick has an extensive background in systems engineering and product development for a variety of systems having worked for Hughes Aircraft and Grumman Aerospace. Recently Ms. Cusick has been involved with the development of the Systems Engineering Capability Maturity Model and the Integrated Product Development Capability Maturity Model as one of the authors for both models. Ms. Cusick has had a significant number of opportunities to observe the problems that companies have been encountering adopting CMMs through participation in a large number of SE-CMM assessments and in the interviews conducted to capture organizational lessons learned as part of the IPD-CMM development process.